REMARKS

This amendment is in response to the office action of May 30, 2008 in which the Examiner rejected the claims over Streetman in view of one or more of the secondary references.

The Examiner's rejection of the claims is respectfully traversed for the reasons set forth below.

Applicant wishes to thank the Examiner for the opportunity to discuss the application on July 11, 2008. No agreement was reached.

The invention is directed to an integrating sphere concentrating photovoltaic cavity converter (PVCC) for wireless power transmission using near diffraction limited, high power lasers. The art cited by the Examiner is mainly directed to conversion of black body radiation, e.g. solar or thermal (incandescent/infrared radiation) energy in to electric power. Radiation from lasers is different from light generated by conventional sources of incoherent radiation. Laser beam is to a very high degree monochromatic and coherent, has very little divergence and is very intense with regard to flux per wavelength and an solid angle units. Thus laser light remains highly collimated and intense over large distances from the laser source, whereas the incoherent radiation diverges strongly and looses intensity with $1/r^2$ away from the source. This is a significant difference in terms of power transmission over larger distances.

It is known to convert laser light to an electrical signal. Although, a communication signals and electrical power are both of electrical nature, the communication signal has traditionally low power and high frequency the electrical power is off much higher wattage and low frequency or is continuous. One mode provides communication signals, the latter provides motive power. Because of the differences between power and signal energy, there are very different problems associated with each.

Although NASA has shown great interest for space applications in the past no one has demonstrated the conversion of high power laser light (1kW to 100kW) into electric power because of the inefficiencies associated with such conversion. This present invention provides very high efficiency at the receiving end. As the efficiencies from electricity to laser light conversion improve steadily the relevance of this invention for space and terrestrial applications will be increasing rapidly.

Streetman shows various embodiments of a thermo-photovoltaic (TPV) converter. In the first embodiment, a gas heated emitter confined within a closed chamber produces incandescent and thermal (near- to mid-infrared) radiation. The radiation falls on a PV cells lining the chamber; and the radiation is converted into electricity. In another embodiment, the chamber is formed with a solar window. The device converts the incandescent/infrared radiation inside the chamber and solar radiation from outside the chamber to electricity. The incandescent light is reflected by the internal surface of the window to prevent loss.

In another embodiment, the incandescent/infrared source and solar source are outside the chamber. The reflective coating on the window is eliminated as unnecessary in such arrangement. Finally, an embodiment like the second embodiment has lenses for focusing the radiation within the chamber.

All of these arrangements represent incoherent radiation converters (sun is considered a near blackbody radiator at 6000 degrees C). Blackbody radiation and laser radiation are profoundly different. The former is broadband in nature whereas the latter is narrow band in nature. In order to efficiently convert the former, it is necessary to provide a broad band PV converter. Whereas, in order to convert the latter, it is necessary to employ a narrow band PV converter.

Most PV converters are relatively narrow band devices. Indeed, the PV industry has made strides in expanding the band width of PV cells

by employing stacked cells, called multi-junction cells, which are configured to convert different bands of energy, say in solar spectrum. Multi-junction cells under investigation are well suited to convert broad band black- or gray-body radiation.

In accordance with the invention, laser light which is at a single frequency can be converted efficiently by employing a cell with an energy bandgap exactly matched to the frequency of the laser. In other words, when the laser and cell are tuned to the same frequency, much of the available energy is converted close to thermo-dynamic limit.

The Examiner has asserted that laser light and black body radiation, e.g. solar or infrared radiation from an incandescent or thermal source, are interchangeable. Applicant respectfully disagrees. While both of these sources are a form of electromagnetic radiation, they have such different characteristics, that they are not interchangeable, particularly in the context of the invention i.e. long distance power transmission via high power lasers. A high quality laser light is coherent and its broadening over long distances can be made near diffraction limited. In other words the beam divergence is very small and the remains collimated over long distances retaining almost all of its energy, where as the intensity (power density) of a blackbody decreases with $1/r^2$, r being the distance from the source.

Streetman shows a thermo-photovoltaic converter and a regular PV converter. Streetman does not teach or suggest anything special for a PV converter. Indeed, everything in Streetman is directed to a conventional PV converter. While concentrating solar devices are known, Streetman makes no suggestion that such a device would be advantageous. Indeed, Streetman employs conventional flat plate technology to collect energy. By this is meant that Streetman only collects light directly from the source and without concentration. If concentration were advantageous to Streetman, surely he would have employed it. Actually Streetman's geometrical concentration ratio with

respect to sun shown in Figure 1 is 0.5. In other words he dilutes the geometric concentration ratio by half.

Laser power beaming for high power generation is only gainful if the laser is a high quality, high power device which produces a relatively powerful beam (1kW to 100kW). However, it is difficult to interface such a high power laser beam with a flat plate PV array. The major problem is the laser flux uniformity across the PV panel due to the Gaussian shaped beam profile. The non-uniformity deteriorates or destroys the PV panel due to reverse biasing of the cells while becoming resistors and heating up according to I^2R rule of ohmic heating. In the present invention an optical interface is provided which reduces the beam size or concentrates focuses the beam to a small beam diameter. The concentrated beam is then coupled to the cavity through a very small aperture. The small aperture allows the light to enter the cavity, but then it traps most of the light. The entrapment process in the cavity creates desired flux uniformity. The light that escapes through the aperture area back into space is proportional to the ratio of the aperture area (A_i) to the area of the cavity (A_s). Accordingly, a concentrated beam of laser energy, having a flux equivalent hundreds to thousands of suns (hundreds to thousands times the amount of un-concentrated sunlight density falling on unit area) enters the cavity.

The interior of the cavity is lined mostly with PV cells having a energy bandgap matched to the laser beam frequency. The light is scattered inside the cavity and photons impinge on the PV cells and are either absorbed and converted or reflected; or the light hits the inside walls of the cavity which are reflective and such reflected light may hit another cell for conversion. Some light is converted to heat by common absorption, representing a loss which is normal but should be kept minimal by having high reflectivity walls and excellent anti –reflective coating and high quality filters on the cells. The invention thus recycles

photons within the cavity until they are converted or lost as waste heat which is minimized by design.

The high radiative power delivered to the cavity results in a corresponding high electrical power output . In order to reduce joule losses (I^2R losses) in the conductors, or grid fingers on the surface of the cells, which collect and carry electrical power from the cells to the bussbars are made wider and thicker to reduce the resistance of these fingers. In terms of flat plate PV receivers this is improvement is significantly limited because the more material that covers the cell the less efficient is the conversion efficiency due to shading of the cell surface by the metal grid as the light that is reflected is lost. However in the case of the cavity converters claimed here, the combination of increased efficiency due to lower resistive losses coupled with photon recycling causes many photons which might otherwise be lost by reflection to be eventually converted after one or more reflections.

Streetman does not show or even suggest such an arrangement. There is no suggestion of concentrating the solar energy in terms of the PV cells. Streetman's overall concentration ratio i.e. the ratio of aperture over the cell area remains the same (0.5). Streetman does speak of using lenses, but the concept is ineffective. The reason for this is that the lenses are inside the cavity and have absolutely no impact to increase the overall concentration ratio. While minor portions of the light inside the cavity might be focused, and thereby locally concentrated, a large portion of the cells are little or not illuminated thus generate no power. This flux non-uniformity between the cell location cause bias reversal and subsequently local heating and damage.. Streetman's design does not serve the major purpose of concentration i.e. using concentration minimize the cell area for a large reflective mirror- or lens area to reduce the cost of the device.

In the present design the total energy is concentrated to a small beam and highly concentrated energy is inserted into the cavity. In

Streetman, an un-concentrated light merely enters the cavity through a large window. Thus the input energy density in Streetman is hundreds to thousands times less than the input energy density of the invention. In other words the present invention reduces the cell cost hundreds to thousands times less. .

The invention therefore combines a high power laser source with a concentrator and a PV cells having a energy bandgap matched to the frequency of the source. The cells are located in a cavity having tiny entrance aperture to allow the concentrated beam to enter, but not escape from the cavity. These features combine to produce high power PV conversion in a highly efficient system.

The art cited by the Examiner makes not suggestion whatsoever for converting laser radiation into power. While the office action asserts that there has been such a teaching, it is respectfully submitted that the art of record shows only the conversion of non coherent blackbody/infrared radiation into electrical power. Two major types of available energy sources are disclosed, namely, solar radiation and thermally induced black body radiation. It is well known to convert solar or thermal/infrared radiation into electrical energy. It is also known to use a PV cell to convert a low power laser (micro- to milliwatt) to produce an electrical signal. What is not known is converting a high power laser (1kW to 100kW) radiation into electrical motive power very efficiently.

The Examiner has asserted that Streetman discloses certain features of the invention. While Applicant disagrees as to the teachings of Streetman, independent claims 1 and 15 have been amended to better clarify the differences between the invention and the reference.

The claims recite that the total aperture area for the cavity is about 0.01 of the internal surface area of the cavity. During the conference with the Examiner, he indicated that the Streetman has an aperture, namely the so called lens elements, and such corresponds to

the aperture in the cavity. The aperture in this context is defined as the area that intercepts the incident radiation which in return determines the total energy intercepted. The plurality of the lenses has no bearing in Streetman's design on the size of the said aperture as it is the equatorial plane area of the sphere. Again, Applicant disagrees as to the characterization and function of the lens in Streetman, but the claim has been amended to recite that the total area of the aperture is limited to a small fraction of the total surface area of the cavity. The purpose of this is to make it clear that the total aperture area for admitting radiation is very small compared to the area of the cavity. Even if Streetman has a lens with a small aperture area, the total aperture area for the device far exceeds the total aperture area of the invention. This very small opening has the effect of facilitating the trapping of light in the cavity.

The amount of light available for conversion to electricity is roughly proportional to (1-Ai/As). Thus, if the total aperture area Ai of the opening is a very small fraction of the surface area As of the cavity then the probability of escape of photons is very small.

It is clear that the aperture area of Streetman is much larger than the small aperture area allowed in the present invention. In all the examples, Streetman has openings for fuel gas and for exhaust. In one embodiment, the housing is a mesh body. Thus Streetman makes no provision trapping the light in the cavity. . In Fig. 1 the apertures are designed to be for gas injection and flu exhaust. Thus their comparison with light apertures is not warranted as they are not designed for efficient optical light coupling into the cavity, but rather meant to be a plumbing feature.

In addition, it is submitted that the function of the aperture has a structural significance. The aperture is sized to trap light. While the reference has a reflective coating on the hemispheric window in Fig. 2, nothing in the reference suggests trapping light by making the entrance aperture small. Indeed, in Streetman, the entrance aperture of the

embodiment of Fig. 2 is almost half the area of the lower half of the sphere. This is needed in order to increase the area available to admit light from the sun.

In this connection, it should be understood that Streetman is not a concentrating collector. Streetman collects only what can be intercepted by the surface area of the sphere. For example, if the surface area of the sphere is one meter square then the total energy available from the sun is limited to the amount of energy in a square meter of sky. In contrast, the invention concentrates laser radiation from a larger area and reduces the beam to a small size so that whatever energy is in the beam is concentrated to a small area. It is contemplated that the concentration ratio is about 500X. This means that the invention collects more than 500 times the energy of Streetman. The concentration Streetman is less than 1X. This feature is recited in the combination claim 15, and the feature is incorporated into amended claim 1. This clearly distinguishes the claims from the reference. Further, Streetman does not suggest any value or advantage for using a concentrator. Indeed, Streetman seems to avoid such an arrangement, choosing instead a conventional flat plate technology equivalent.

The other references which employ concentrators are for non coherent black body or infrared radiation and none suggest that a laser beam should be exchanged with conventional broadband sources.

In view of the foregoing, it is respectfully requested that the Examiner reconsider his rejection of the claims, the allowance of which is earnestly solicited.

If additional fees are required, the Commissioner is authorized to charge Deposit Account 504147 for such fees or credit any overpayment thereto.

Respectfully submitted,
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